Polarization-dependent imaging of domains, critical phenomena, and dynamics using X-Ray Photoemission Electron Microscopy

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X-ray Photoemission Electron Microscopy (X-PEEM) is a surface imaging technique, which uses photoelectrons and secondary electrons created by the absorption of x-rays. A resolution of a few ten nanometers is typical for X-PEEM while newest, aberration corrected instruments promise to reach low nanometer resolution. Element-, chemical-, local symmetry-, and magnetic-contrast imaging exploit the tunability, high energy resolution, polarization control, and stability provided by modern x-ray beamlines. While not brightness limited, focusing of the x-rays allows us to reach high frame rates in X-PEEM experiments.

In the first half of this presentation I will discuss current trends in the technical development of X-PEEM, in particular aberration correction, cryogenic imaging, imaging of fast dynamics, and time-lapse imaging using fast CCD detectors. Today, the X-PEEM technique is being applied to a wide variety of materials and scientific problems and flexibility in regard to the environment, to temperature, magnetic fields, electric signals, and spectroscopic probes is as important as the spatial resolution of the instrument.

In the second part I will showcase several science examples that exploit polarization-dependent contrast. Ferroelectrics and multiferroics are seen as tools to control magnetism using electric fields, drastically reducing the energy required to switch a magnetic element and providing a direct, localized handle to the magnetic state. Starting with first experiments that demonstrated the ability of X-PEEM to measure the magnetic and ferroelectric domain state, I will show how PEEM imaging allowed researchers to build and characterize more and more sophisticated multiferroic systems, which bring us closer today to controlling nanoscale magnetic moments in a capacitive device that requires no currents [1,2].

Linear dichroism imaging has had great influence on our knowledge of the antiferromagnetic domain state but it is equally useful in structural studies with sub-micron spatial resolution. Using polarization dependent X-PEEM, researchers were able to disentangle the chemistry and orientation of crystallites in calcium carbonate biominerals, giving us important information about the morphology and growth of these materials. I will present some of the latest results on natural materials existing in shells and tunicates [3].

The ability of X-PEEM to rapidly map large areas with high resolution has been used in multiple studies of fluctuations and relaxations in artificial spin ice systems. Artificial spin ice systems that are made of nanoscale magnetic patterns are thermodynamical model systems that replicate frustrated lattices of atomic magnetic moments, for example of pyrochlore spin ice. X-PEEM imaging has been instrumental in allowing us to go beyond static imaging of glassy spin ice towards measuring thermally active systems that relax and fluctuate on time scales of milliseconds to hours [4].

[1] Heron, J.T., et al., Nature 516(7531), 370-373 (2014).
[2] Sohn, H., et al., ACS Nano 9(5), 4814-4826 (2015).
[3] Devol, R., et al., Journal of Physical Chemistry B 118(28), 8449-8457 (2014).
[4] Kapaklis, V., et al., Nature Nanotechnology, 104 (2014).